Collapse and Outflow: Towards an Integrated Theory of Star Formation

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Abstract.

Observational advances over the last decade reveal that star formation is associated with the simultaneous presence of gravitationally collapsing gas, bipolar outflow, and an accretion disk. Two theoretical views of star formation suppose that either stellar mass is determined from the outset by gravitational instability, or by the outflow which sweeps away the collapsing envelope of initially singular density distributions. Neither picture appears to explain all of the facts. This contribution examines some of the key issues facing star formation theory.

1. Introduction

How stars form is one of the most important unsolved problems in astrophysics. It has turned out that the process is surprisingly rich, involving the formation of dense cores in magnetized molecular clouds, gravitational collapse, the ubiquitous presence of accretion disks around young stellar objects, and most surprisingly perhaps, the presence of high speed bipolar outflows and jets. While gravitational collapse and the formation of disks might have been expected in any model of star and planet formation, the role of bipolar outflows has yet to be fully integrated into our thinking.

Star formation theory has scored some notable successes, among them being the elucidation of the importance of magnetic fields, and the physics of gravitational collapse and of magnetized outflows from the central engine. In spite of these advances however, there is still no generally accepted answer to the most basic question of all; what determines the mass of a star? In this review, we discuss some of the main ideas of star formation with a view to addressing this question. Its solution will no doubt require sophisticated mathematical and numerical tools.

1.1. Basic Facts

Star formation occurs within very specific, over dense regions within molecular clouds known as molecular cloud cores (Benson & Myers, 1989). The physical

conditions within these cores presumably provide the initial conditions for star formation. One of the most basic properties of cores is that their mass distribution is very well defined. Measurements indicate that the clumps and cores within molecular clouds obey a well defined relation in which the number of cores per unit mass scales as

$$dN(m)/dm \propto m^{-\alpha},$$

where the index $\alpha = 1.6 \pm 0.2$ (e.g., Blitz 1991).

The internal structure of cores has been intensively studied in the last decade. Molecular cloud cores are known to be prolate structures (Myers et al. 1991) in which rotation is insignificant in comparison with the self-gravity of the core. The line widths in molecular cloud cores *increase* as one moves outwards to larger radii; thermal gas pressure can dominate only in the inner-most regions (.01-pc scales) in cores (Fuller & Myers 1992; Caselli & Myers 1995). Nonthermal motions dominate on larger scales in cloud cores, with the nonthermal velocity dispersion in low mass cores scaling as

$$\sigma_{NT} \propto r^{0.5} \;,$$

while for higher mass cores

$$\sigma_{NT} \propto r^{0.25} \;.$$

These relations *appear to hold for both starless and star-containing cores*. We therefore appear to be seeing the initial conditions for star formation. Several theorists argue that this is misleading and that all cores are already affected by outflows from newly formed stars. If the nonthermal line width in cores is produced by the interaction of bipolar outflows with their surrounding core gas, then it has been argued that one could construct a model for the stellar initial mass function or IMF (e.g., Silk 1995).

The source of energy that is sufficient to balance gravity within molecular clouds and their cores is the magnetic field that threads them. Zeeman measurements show that molecular cloud and core fields have energy densities comparable to gravity (Myers & Goodman 1988, Heiles et al. 1993). The nonthermal line widths would presumably reflect a generic MHD turbulence, or perhaps superposition of MHD waves in clouds. No general theory for how such MHD turbulence might be excited yet exists, although outflows have been suggested as a possible source of excitation.

Of central importance for an integrated theory of star formation is an understanding of why outflow and collapse are operative at the same time as a star forms. The so-called Class 0 sources, which are objects having virtually no emission at wavelengths below 10 μm, and spectral energy distributions characterized by single blackbodies at $T \simeq 15 - 30$ K, are important in this regard. There is some evidence to suggest that these are protostars whose collapsing envelopes may exceed the central protostar in mass suggesting an age of $t \simeq 2 \times 10^4$yrs in some models (e.g., André, Ward-Thompson, & Barsony 1993; but see Pudritz et al. 1996). The key point here is that such objects have particularly strong and well collimated outflows (e.g., Bontemps et al. 1996).

Finally, infrared camera observations of embedded young stellar objects within molecular cloud cores indicate that stars don't form individually, but as

members of groups and clusters. Almost of necessity, the most detailed available calculations of star formation focus on the formation of individual stars. However, this theoretical focus may be blinding us to the solution to our basic question.

1.2.   Basic Ideas

Theoretical thinking about the star formation process stems from two fundamental, but quite different aspects of the physics of self-gravitating gas clouds. The first view is that stellar mass is determined by gravitational instability, while the second is that it is determined by shutting off accretion in collapsing cores. There are persuasive arguments for and against both of these pictures.

Gravitational instability: One of the classic calculations is Ebert (1955) and Bonnor's (1956) analysis of the stability of an isothermal sphere of self gravitating gas of mass M that is embedded in an external medium with a pressure P_s. The critical mass for a cloud at temperature $T = 10$ K and supported purely by thermal gas pressure, is

$$M_J = \frac{1.2(T/10 \text{ K})^2}{(P_s/10^5 k_B \text{ cm}^{-3} \text{ K})^{1/2}} \ M_\odot \ .$$

It is impressive that this argument picks out a solar mass so that one can say that self-gravitating gas at 10 K naturally forms solar mass objects (e.g., Larson 1992). The 10 K temperature arises from the balance of cosmic ray heating and cloud cooling by millimetre radiation from collisionally excited CO molecules (Goldsmith & Langer 1978). The Jeans mass is significantly larger in turbulent media, where turbulent rather than purely thermal pressure enters into the above expression (eg. Mckee et al. 1993).

There are several problems with this view however. There doesn't seem to be an obvious way of explaining the initial mass function of stars, which ranges over two decades in mass. Why wouldn't the clump mass spectrum be the same as the IMF in this theory? The measured mass spectral index for the IMF is $\alpha_* = 2.35$ (Salpeter 1955). Thus, while the total gas mass in the CMF is dominated by its most massive core, the stellar mass in the IMF is dominated by the low mass end. This fact suggests that many low mass objects prefer to form in the more massive clumps; i.e. cluster formation is required (Patel & Pudritz 1994). Secondly, the role of outflows seems incidental to the process except insofar as it removes the angular momentum of collapsed core gas allowing the star to form via accretion through the disk.

Truncating the collapse: An equally fundamental view of a self-gravitating cloud is that the accretion rate in the collapse of singular isothermal spheres is fixed by molecular cloud core conditions (e.g., Shu 1977). For an isothermal equation of state, the accretion rate is a constant,

$$\dot{M} = 0.975 \frac{a_{eff}^3}{G} = 1.0 \times 10^{-5} \left(\frac{a_{eff}}{0.35 \text{ km s}^{-1}} \right)^3 \ M_\odot \text{ yr}^{-1}$$

where a_{eff} is an effective sound speed in the core. In these self-similar theories, gravitational collapse and accretion onto a central protostar can go on

indefinitely. Mass must therefore be fixed by the mechanism that truncates the accretion phase such as jets and outflows. This view is interesting because it incorporates outflow into the basic mechanism of star formation.

This view also has its problems. As with the first theory, there seems to be no obvious way in which an IMF could be produced. The role of the CMF is equally mysterious. Secondly, while jets do pack considerable power, they also appear to be highly collimated. This is especially true of outflows associated with the so-called class 0 sources. An outflow that doesn't cover a fair fraction of 4π is unlikely to be able to eject the remains of a collapsing envelope. Such material could still end up on the disk, and accrete from there onto the central star.

2. Initial States

The basis for the gravitational instability picture arises most simply in the model worked out by Bonnor and Ebert. Consider applying an external surface pressure P_s on an isothermal cloud of mass M. Calculate the structure of the resulting clump that is in hydrostatic balance with its own gravity and internal pressure P and the external pressure. For such pressure bounded equilibria, we may ask the question, at what radius R will one find pressure balance between clump pressure and P_s? This problem is solved by finding solutions to the Lane-Emden equation for these truncated configurations. If one now asks for the characteristics for our isothermal, non-magnetic cloud, that is *critically stable* $(dP_s/dR = 0)$, Ebert and Bonnor found that

$$M_{crit} = 1.18 \frac{\sigma_{ave}^4}{(G^3 P_s)^{1/2}}$$

$$\Sigma_{crit} = 1.60(P_s/G)^{1/2} .$$

These models have a finite central density and attain a $\rho \propto r^{-2}$ structure at large radii.

The generalization of this analysis for arbitrary equations of state may be found in McLaughlin & Pudritz (1996), where one finds that the expressions for M_{crit} and Σ_{crit} for clouds with any equation of state will differ from the isothermal, Bonnor-Ebert ones at the $< 10\%$ level; the physical scalings remain the same. (The effect of the equation of state is to modify the numerical value of the line width σ_{ave}; see McLaughlin & Pudritz 1996.) The gradual loss of magnetic flux by ambipolar diffusion implies that cores are supported against gravitational collapse in their innermost regions for about ten free fall times. As long as the central regions of cores are magnetically supported, their central densities continue to grow slowly. Detailed calculations show that once a critical value of the ratio of the gas mass to magnetic flux in the central region is surpassed, then the central density profile of magnetized cores begins to approach a singular solution more rapidly. During this more dynamic phase, collapse probably begins before a singular state is actually achieved (e.g., Basu & Mouschovias 1994).

Shu (1977) and Li & Shu (1996) argue that this steepening of the density profile continues until the density actually becomes singular. In this event, which

occurs say at time $t = 0$, its structure is simply described by the relation;

$$\rho(r) = \frac{\sigma^2}{2\pi G} \, r^{-2} \; .$$

This singular distribution has a finite mass at the centre (related to a numerical constant, m_o). Once it is achieved (in finite time), it is impossible for gas in the vicinity of the newly-formed protostar to evade gravitational collapse. Thus the the main accretion phase in singular isothermal sphere (SIS) models, consists of an "inside-out" collapse of the envelope onto this protostar. The evolution during this phase is then best discussed in terms of an outwards-moving collapse front — the so-called "expansion wave."

2.1. Equations of State

A theoretical model of star formation in more massive cores must incorporate some means of describing the nonthermal motions. One way of proceeding is to model the gas with an effective equation of state (EOS). If one resorts to polytropic models as an example, then the total line width scales as $\sigma^2 \propto P/\rho \propto \rho^{\gamma-1}$. Now since the lines are observed to broaden as one goes to larger physical scales (where the density is decreasing), then this simple result requires models with $\gamma < 1$, which brings up the idea of negative polytropic indices (Maloney 1988). Lizano & Shu (1989) modeled the general structure of cores by breaking the pressure up into isothermal and turbulent contributions; $P = P_{iso} + P_{turb}$. In order to handle the turbulent motion, they suggested a so-called logotropic relation (their words) between turbulent gas pressure and density; $P_{turb} = \kappa \, \ln(\rho/\rho_{ref})$. On the other hand, McKee & Zweibel (1995; see also Pudritz 1990) later noted that a gas dominated by the pressure of Alfvén waves would have an effective EOS of the form $P_{wave} \propto \rho^{1/2}$.

The data of Caselli & Myers (1995) provides a way of testing possible EOS. The challenge is to fit the trends in both the low and higher mass cores using a single EOS. McLaughlin & Pudritz (1996) found that the models mentioned above did not fit the data. Their best fit is achieved by the so-called pure logotrope,

$$P_{total}/P_c = 1 + A \, \ln(\rho/\rho_c)$$

$$A \simeq 0.2 \; ,$$

in which the *total* gas pressure $P_{iso} + P_{turb}$ has a logarithmic dependence on density. In the singular limit, these models have density profiles that are much shallower than SIS models;

$$\rho(r) = (AP_c/2\pi G)^{1/2} \, r^{-1} \; .$$

Figure 1 shows the fit of the pure logotrope to observed line widths inside cores, and illustrates how well constrained the value of the coefficient A is. The vertical lines mark the radius of the critically stable model. Unmagnetized logotropes have critical masses of $92M_{\odot}$ while magnetized ones have critical masses of $250M_{\odot}$. Such cores are obviously far more massive than $1M_{\odot}$, and must therefore be the objects in which multiple star formation occurs. Since solar mass clumps fall far below the critical mass for a logotrope, their internal
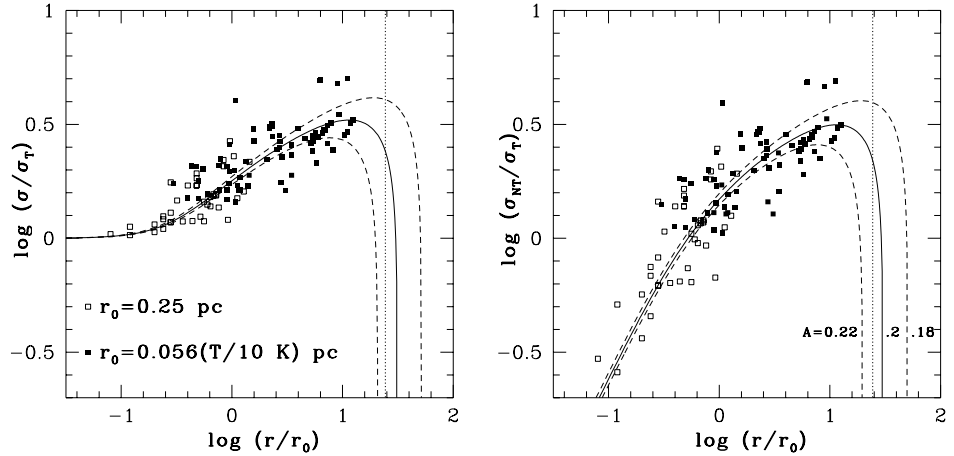
Figure 1.   Total line width σ, and turbulent component σ_{NT}, relative to the thermal contribution σ_{T}. Data on low mass cores (*open symbols*) are referred to a larger scale radius than high mass cores (*filled symbols*); the former are less centrally concentrated. Curves are the predictions of the logotropic EOS, for three values of the parameter A; vertical lines mark the radius of a critical-mass, $A = 0.2$ logotrope (from McLaughlin & Pudritz 1996).

structures are dominated more by gas pressure than by gravity. Thus, they are less centrally concentrated than higher mass clumps, and this is reflected in their larger scale radius r_o in Figure 1. Note that star formation appears to be occurring in a wide variety of these clumps which suggests perhaps that the gravitational instability analysis may have less to do with the issue of stellar mass determination than does the accretion picture.

3.   Gravitational Collapse

Insight into gravitational collapse in molecular cores has been gained by considering special cases that are analytically tractable such as the collapse of SIS models. Non self-similar models, such as the Bonnor-Ebert solutions, require a detailed numerical solution. Thus, Foster & Chevalier (1993) investigated the collapse of Bonnor-Ebert spheres and found that their numerical solutions produced supersonic velocities during initial stages of the collapse. Central inflow speeds reached -3.3 times sound speed, and a central density distribution $\rho \propto r^{-2}$ developed. Their work generalizes the collapse calculations of Larson (1969) and Penston (1969) who began with uniform spheres. The difference in the results is that Foster & Chevalier find that supersonic speeds develop only in a small region in the centre, and not throughout the model. Also, the mass accretion rate is constant only if the initial configurations are very highly centrally concentrated.

Following Larson (1969) and Shu (1977), it is convenient to define similarity variables; if a_t (in general, time dependent) is the sound speed, then the self-

similar dimensionless length is $x = r/a_t t$. The equations of motion then imply an accretion rate

$$\dot{M}(0,t) \propto a_t^3/G \ .$$

In what follows, we take the extreme cases of the SIS (Shu 1977) and the singular, pure logotrope models (McLaughlin & Pudritz 1997). The different character of the self-similar collapse solutions for these two different models well illustrates the effect that the EOS has upon the physics of the collapse. For the SIS model, the position of the expansion wave (see §1.2) in the self-similar variable x is always located at $x_{exp} = 1$. The expansion wave moves outwards through the undisturbed envelope at constant speed $a_t = a$; its position at any time is then $r_{exp} = at$, and the mass of the central protostar grows as

$$M = m_o a^3 t/G \qquad m_o = 0.975 \ .$$

For the logotrope on the other hand, the expansion wave is located at $x_{exp} = 1/4\sqrt{2}$ and the sound speed is no longer a constant; $a_t = [AP_c 4\pi G]^{1/2} t \propto t$. The position of the expansion wave in space is $r_{exp} = a_t t/4\sqrt{2} \propto t^2$ and the mass of the protostar grows as

$$M = m_o [AP_c 4\pi G]^{3/2} t^4/G \qquad m_o = 0.667 \times 10^{-3} \ .$$

The infall speed at any time is lower for the logotrope than for the SIS model because the latter has a more centrally concentrated density profile. Note also that the numerical constant m_o which scales the initial protostellar mass at the instant $t = 0$ is much smaller for the logotrope. This has the consequence that it takes much longer to grow low mass protostars.

One of the main results of McLaughlin & Pudritz (1997) is that the time required to accumulate a solar mass star is of order 2×10^6 years, which is much longer than for an SIS model. On the other hand, all stars in the logotrope picture accumulate in the roughly the same time which is not true of SIS models. This has a major impact on our ideas of IMF formation. It suggests that star formation in the logotropic picture, must really be sequential in time. Indeed, any theory for the formation of star clusters must guarantee that low mass star formation gets started first, since when massive stars turn up, the molecular cores will be obliterated. While SIS models could only pertain to low mass cores, high mass star formation necessarily takes place in more turbulent conditions so that star formation time scales are much shorter (eg. Myers & Fuller, 1992). Thus, here too, sequential star formation needs to be invoked.

4. Outflows

Episodic jets are observed in AGNs, regions of star formation (e.g., Edwards et al. 1993), and binary systems with black holes. Whenever one observes a jet, there is good evidence that an accretion disk is also present; a fact that is probably not fortuitous. Young stellar objects have associated outflows that last a long time, at least $1-2\times10^5$ yrs according to Parker et al. (1991). The outflows in Class 0 submm sources have mechanical luminosities that rival the accretion luminosity of the central object with $L_{mech} \simeq L_{bol}$. In all outflows, radiation

pressure fails by several orders of magnitude to provide the observed thrusts in winds so that mechanisms involving magnetic drives seem to be suggested.

Current models for outflows invoke magnetic fields that thread Keplerian disks. They are of two types; (i) *hydromagnetic disk winds* wherein the engine consists of a Keplerian disk threaded by a magnetic field that is either generated in situ, or advected in from larger scales (e.g., Blandford & Payne 1982; Camenzid 1987; Lovelace et al. 1987; Heyvaerts & Norman 1989; Pelletier & Pudritz 1992; Li 1995; Appl & Camenzid 1993; Königl & Ruden 1993); or (ii) *X winds*, which are magnetized stellar winds where the interaction of a protostar's magnetosphere with a surrounding disk results in the opening of some of the magnetospheric field lines (Shu et al. 1987, 1994).

Perhaps the most important difference between these two classes of models lies in the role of the central object. For disk winds, only the depth of the gravitational well created by the central object is of any importance. The energy source for the flow is the gravitational energy release of material in the Kepler disk as the wind torque extracts its angular momentum. This view implies that the physics of jets from the environs of protostars, or black holes is essentially the same. For X wind models on the other hand, the magnetization and structure of the central object is critical. Its magnetic field strength must be sufficient to carve a magnetosphere inside the disk and outflow requires that the magnetopause and co-rotation radii of the star are virtually identical; $R_m \simeq R_{co}$.

These two different wind mechanisms make different predictions about the possibility of truncating the collapse of the surrounding envelope. The X-wind model has a low density, radial component to the wind that could possibly clear out the envelope. Disk wind simulations, such as those of Ouyed, Pudritz, & Stone (1997) and Ouyed & Pudritz (1997 a,b) (see below) find that a finite fraction of the disk is involved in outflow and that outflows are rapidly collimated towards the outflow axis. This implies that they may not be able to clear out the envelope. As far as we are aware, extensive calculations of this type have never been done in either of these theoretical models so the jury is still out.

Numerical simulations of disk winds by Ouyed et al. (1997; see also Ouyed, 1977) were run in order to test the predictions of steady state theory and to see whether or not time-dependent calculations would yield jets that are truly episodic. The simulations have an initial state consisting of a central point mass, the surface of a surrounding Keplerian accretion disk (inner radius r_i), and a disk corona that is in exact (analytical and numerical) hydrostatic balance in the gravitational field of the central object and in pressure balance with the accretion disk below. The disk and corona is threaded by a magnetic field configuration chosen to have initial current $\mathbf{J} = 0$ so that no magnetic force is exerted initially upon the corona. Two different magnetic configurations were investigated; the first was a vacuum solution for a field with a conducting plate at its base (called a potential distribution), and the second was a constant uniform magnetic field that is parallel to the z-axis and perpendicular to the disk. This second configuration was chosen because no outflow is expected in steady state theory. The models depend on 5 parameters; three prescribe the initial corona (ratio of gas to magnetic pressure, thermal to rotational energy density, and the ratio of the density of the base of the corona to disk density; all these measured at r_i), one gives the ratio of the toroidal to poloidal field strength in the disk,

and a final parameter measures the speed at which mass is injected from the disk into the base of the corona. This latter speed is taken to be a thousandth of the local Kepler speed, or a hundredth of the disk sound speed. All lengths in our simulations are in units of r_i, and all times (τ) are in units of the Kepler time $t_i = r_i/v_{K,i}$ at the inner edge of the disk.

Simulations using the potential field configuration (see Ouyed et al. 1997, Ouyed 1977) clearly show a bow shock that separates the outflow that has started from the disk, with the undisturbed corona. The field lines and flow behind the bow shock are collimated towards the z axis into a jet-like, cylindrical out-flow. The result shows that a cylindrically collimated, stationary outflow is achieved. Cylindrical collimation is predicted to be a generic feature of magne-tized outflows in which the dominant toroidal field of the outflow together with its associated current (which flows up the jet) together exert a pinching Lorentz force towards the outflow axis (e.g., Heyvaerts & Norman 1989). Ouyed et al. also show the position of the Alfvén and fast magnetosonic (FM) surfaces where the outflow speed achieves the propagation speeds of two of the three impor-tant wave speeds in magnetized gas. The data are compared with the position of the Alfvén point on each field line in the simulation as predicted by steady state theory (e.g., Blandford & Payne 1982). The agreement is very good. This and many other diagnostics (see Ouyed et al. 1997) show that there is good agreement with steady state disk wind theory and our simulations. While this is important and interesting, nature prefers to produce highly time-dependent, episodic outflows. Why is this?

Figure 2 shows that outflow occurs even for our initially uniform magnetic field configuration. The highly collimated, jet-like outflow is in this case, domi-nated by a series of dense knots that are produced periodically on a time scale of $t_{knot} \simeq 11t_i$. Knots are produced in a generating region close to the central source; at a distance $z_{knot} \simeq 6 - 7r_i$. Knots continue to be produced for as long as we have run our simulations, up to 1000 time units, and so they are truly generic and are not transients. Figure 2 shows three snapshots of a highly zoomed-in simulation ($(z \times r) = (20 \times 10)r_i$) designed to show the details of the knot generating region. The left panels show the poloidal magnetic field structure of the flow at three times during which a new knot is formed. The right panels show the opening angle of the magnetic field lines as a function of their footpoint radius r_o on the surface of the accretion disk. One sees from these graphs that the field lines have been pushed open in a small region of the disk, making an angle of $50° - 60°$ with respect to the disk surface. These field lines have been opened up by the toroidal magnetic field pressure arising from the Keplerian rotation of each field line. Since Kepler rotation is faster at smaller radii, one expects that torsional waves introduce stronger toroidal field into the corona at smaller radii. This creates the radial gradient in toroidal field pressure that opens the field lines to less than the critical angle of 60° from the axis (Blandford & Payne 1982).

We found that knots are produced whenever the toroidal field in this inner region is sufficient to recollimate the newly accelerated gas back towards the outflow axis (see Ouyed et al. 1997). The gas necessarily speeds up. Because the gas is rotating however, it encounters a centrifugal barrier at $r \geq r_o$. As it reflects off of this barrier, it collides with the slower gas around it and shocks.
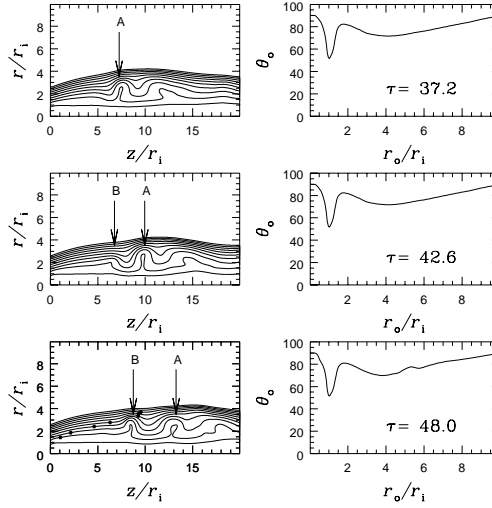
Figure 2. The left panels show the magnetic field structure of the knot generating region, at the three times; 37.2, 42.6, and 48.0 inner time units. The right panels show the angle θ_o of field lines at the base of the flow, with the disk surface, at these times. Note the narrow band of field lines which is sufficiently opened ($\theta_o \leq 60°$) so as to drive the outflow. Only field lines involved in the knot generation process are shown; field lines at larger disk radius stay reasonably vertical as seen in the right panels (from Ouyed et al. 1997).

The shocked gas regions move away from this generator region, and are kept coherent by strong enhancements of the toroidal field both ahead of it, and behind it. The knots, which are the overdense regions, have low toroidal field strengths, and conversely, the space between the knots is dominated by high toroidal field strength. The time scale for the passage of an Alfvén wave (in the toroidal field) from the jet radius towards the axis and back again, turns out to be precisely the knot generation time. This episodic behaviour of jets may reflect on the nature of the accretion disk that is feeding gas into the corona. If the entry ram pressure of newly injected material in the corona, exceeds the toroidal field at the base of the corona, then we found that the outflow develops into a stationary flow. Thus, the general time-dependent behaviour of episodic jets may be intimately related to conditions in the underlying accretion disks. One must ultimately remove the constraint of keeping the disk as a fixed boundary condition in the problem if one hopes to explore this idea by numerical simulation.

5. An Integrated Model?

What general points about an integrated star formation theory arise from these considerations? Perhaps the least controversial point is that accretion disks may be the glue that binds outflow and infall together. Outflows may commence as soon as the collapse has been sufficient to create even a tiny, centrifugally sup-

ported region in a disk (e.g., Pudritz et al. 1996). Accretion of infalling material onto and through the disk will drive the outflow. Thus, the continuous feeding of the disk by the infalling envelop should help to sustain a vigorous outflow. It is completely unclear as to whether or not the details of the gravitational collapse are important for the formation of an outflow (e.g., singular logrotropic vs. isothermal collapse; or non-self-similar collapse). It is sobering to note that no self-consistent numerical simulation of collapse that we are aware of has shown that outflows are produced. If outflows are disk winds, then their efficient removal of disk angular momentum would help to drive an accretion flow through the disk. Of course, significant turbulent disk viscosity, such as could be produced by MHD Balbus-Hawley (1991) turbulence, could also transport disk angular momentum (radially). The high collimation of hydromagnetic disk winds makes it unlikely that they will clear out the infalling envelope. X-winds, if they occur, may have less of a problem in this regard.

While many details need to be checked before any useful predictions can be made, we suggest from all of this that the physical processes of collapse and outflow at the level of the formation of an individual star, have no obvious means of dictating the mass of a star. If this is correct, then the answer to our basic question must take place in more general, larger scale processes. Thus, the idea that stars form as members of groups and hence must somehow compete for their gas supply, may be of central importance to the theory of star formation.

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